

3.3 Yield and atom economy

Name: _____ Class: _____ Date: _____

Total: 20 marks

KEY WORDS percentage yield • atom economy

Objective

Calculate percentage yield and atom economy with the reasons yields fall. Chemistry only. Original questions for spec statement 4.3.3.

1 Key knowledge and worked examples

Yield is below 100 % because: the reaction is **reversible**; product is **lost in separation**; reactants react in **unwanted side reactions**.

$$\% \text{ yield} = \frac{\text{actual mass}}{\text{theoretical mass}} \times 100$$

$$\text{atom economy} = \frac{\text{coefficient} \times M_r(\text{desired product})}{\sum [\text{coefficient} \times M_r(\text{reactant})]} \times 100 \%$$

High atom economy = more starting material becomes useful product – better for **sustainable development** and cost.

Worked example (4 marks). 4.0 g of product is obtained where theory gives 6.4 g. Calculate the percentage yield.

$\% \text{ yield} = 4.0 \div 6.4 \times 100 = 62.5 \%$. The shortfall comes from losses in separating the product or incomplete/reversible reaction; atom economy is a different measure – it counts the fraction of reactant mass ending in the desired product.

2 Practice

2.1 Give two reasons why yield is below 100 %. [2]

2.2 Theoretical mass 25 g, actual 20 g – percentage yield? [2]

2.3 Why do industries prefer high-atom-economy processes?

[1]

3 Exam-style questions

3.1 A reaction should give 12.0 g of product; 8.4 g is made. Calculate the percentage yield and explain two likely reasons for the loss.

[4]

3.2 Hydrogen is made from methane and steam: $\text{CH}_4 + \text{H}_2\text{O} \rightarrow \text{CO} + 3 \text{H}_2$ (C = 12, H = 1, O = 16). Calculate the atom economy when hydrogen is the desired product.

[4]

3.3 State the difference between percentage yield and atom economy.

[3]

3.4 For the same desired product, route A has 90% atom economy, 40% yield and prolonged heating. Route B has 75% atom economy, 95% yield and a saleable by-product. Evaluate the routes using the data and identify one further piece of evidence needed.

[4]

Solutions

2.1 Any two of: reversible reaction does not go to completion; product lost on separation from the mixture; reactants react in unwanted/side reactions.

2.2 $20 \div 25 \times 100 = 80 \%$.

2.3 Fewer raw materials are wasted and less needs disposing of – sustainable and cheaper.

3.1 $8.4 \div 12.0 \times 100 = 70 \%$. Reasons: the reaction may be reversible and stop before completion; some product is lost when separated/filtered/purified; some reactants may react differently in side reactions.

3.2 $\text{Mr}(\text{CH}_4) = 16$, $\text{Mr}(\text{H}_2\text{O}) = 18 \rightarrow$ reactants total 34; Mr of desired product = $3 \times 2 = 6$ for the hydrogen; atom economy = $6 \div 34 \times 100 = 17.6 \% \approx 18 \%$.

3.3 Percentage yield compares what was actually made with what could theoretically be made from the reactant used – an experimental measure. Atom economy compares the coefficient-weighted relative mass of the desired product with the total coefficient-weighted relative mass of reactants from the equation – a property of the reaction itself. A reaction can run at 100 % yield yet low atom economy if by-products form as the only other outcome.

3.4 A directs a greater fraction of reactant mass to the desired product, but B recovers a greater fraction of its own theoretical product. Give a qualified judgement linking heating/energy or useful by-product to the supplied tradeoff; request relevant cost, energy, reactant quantity, rate, waste or actual by-product demand data. The percentages alone do not establish which gives more product per batch: theoretical amounts are not supplied.